# A New Method to Understand the Momentum Aperture in Particle Accelerators

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Storage rings are used for a variety of science and technology applications - for example as synchrotron light sources or as colliders for particle physics. In these storage rings, bunched particle beams circulate for many hours. The motion of a particle can be described in terms of transverse (betatron) and longitudinal (synchrotron) motions with respect to the reference particle. Some particles may be lost due to various aperture limitations. The momentum aperture is defined as the maximum momentum deviation that a particle can have without becoming unstable and being lost. The momentum aperture is determined by the complex 6-dimensional dynamics of the particle. Because of the complexity of the dynamics, up to now there have been unexplained discrepancies between the predicted and measured momentum aperture.

In many cases the momentum aperture is the dominating factor determining the beam lifetime. Long lifetimes are desirable to users of synchrotron light sources since they increase the integrated photon flux, reduce the frequency of refills, and improve the stability by reducing thermal effects. In those storage rings where the dominant lifetime process is Touschek scattering, the lifetime has a stronger than quadratic dependence on the momentum aperture. The Touschek lifetime at the ALS of 9 hours is much shorter than the vacuum lifetime of 60 hours, so the ALS would benefit greatly from a larger momentum aperture. Therefore it is important to understand what limits the momentum aperture. This knowledge will help improve the performance of existing light sources as well as to help predict and optimize the performance of future storage rings.

The particle dynamics [1,2] and momentum aperture [3] have been extensively studied at the ALS. A schematic of the process leading to particle loss after Touschek scattering is shown in Fig. 1. Due to Touschek scattering a particle receives a certain energy offset (here 3%). If the scattering happens at a position of the ring with dispersion, this energy change will also induce a transverse oscillation (red circle). Due to the tuneshift with energy (chromaticities) and tuneshift with betatron amplitude, the betatron tunes (i.e. the number of transverse oscillations in one revolution) of the particle change as well (right part of the figure). Afterwards, the particle undergoes energy oscillations and slowly damps back to the nominal orbit (green circle). Because of the chromaticities and the tuneshift with amplitude, the tunes get modulated during this process and eventually the particle might encounter a resonance or an area of high diffusion and might be lost.

Tracking particle trajectories using a realistic representation of the ALS lattice confirmed that the model of particle loss mentioned in the previous paragraph is correct. Fig. 2 shows the trajectory of a particle tracked for 10,000 turns including the effects of synchrotron radiation. On the left side, you can see the horizontal and vertical position of the particle. On the right side the betatron tunes are shown (calculated every 300 turns). At certain times (a)-(c) when the tunes cross resonances, growth of the oscillation amplitude is observed. On some of those occasions, the particle got very close to the vacuum chamber (±4 mm). Particles with slightly different initial conditions can be lost.

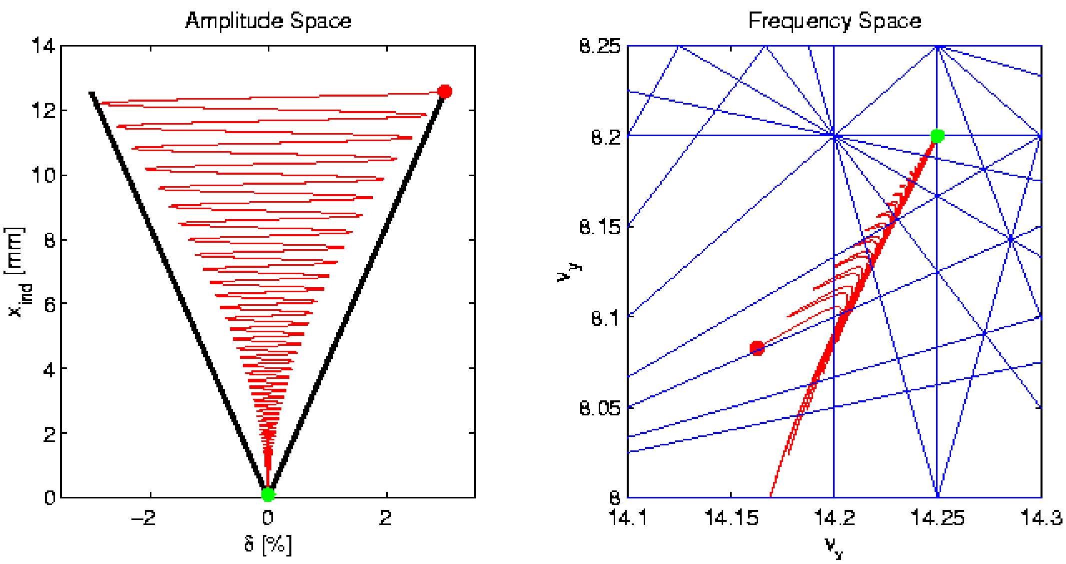


Fig 1: Left: Schematic of particle behavior after Touschek scattering. Initial particle position after being scattered (red circle) then oscillating in energy and amplitude (solid line) and damping back down to the nominal orbit (green circle). Right: particle motion tracked in the tune space $\nu_x$, $\nu_y$, showing the effect of tune shift with betatron amplitude and tune shift with energy. Resonances up to the fifth order are shown.

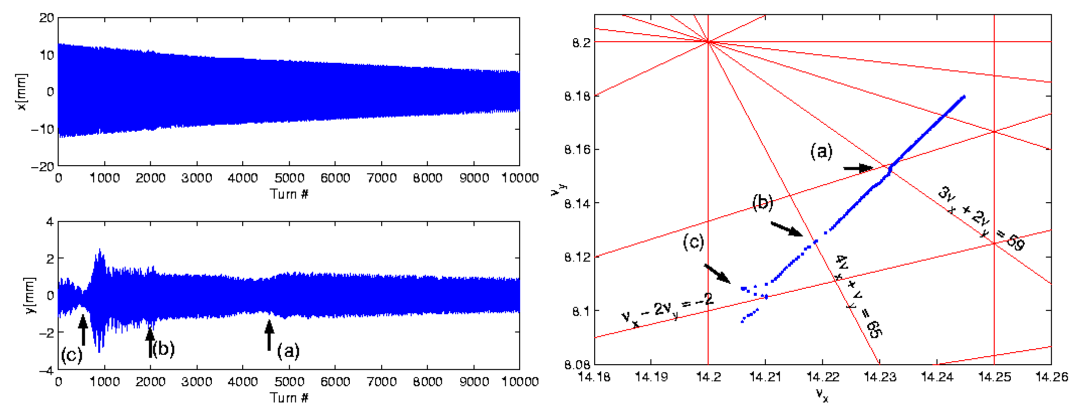


Fig 2: Tracking of a particle with synchrotron oscillations and radiation damping (in tune and configuration space). When the trajectory crosses a region with high diffusion (see labels (a) to (c)), the vertical oscillation amplitude increases and at (c) the particle gets very close to the vacuum chamber aperture of 4 mm.

The main tools to understand the momentum aperture are two classes of measurements. Both methods clearly show that the major limitation to the momentum aperture is the transverse beam dynamics, causing Touschek scattered particles to eventually reach large vertical amplitudes where they are lost on the vacuum chamber (compare ALS activity report 2000). Analysis of the measurement data using Frequency Map Analysis allows us to understand the details of the beam loss - identifying those resonances that limit the momentum aperture. One example using the nominal ALS lattice is shown in Fig. 3. The left plot shows relative beamloss in the configuration space formed by energy offset and horizontal oscillation amplitude. One can clearly see the complicated structure of the boundary of the stable area. The right plot shows the

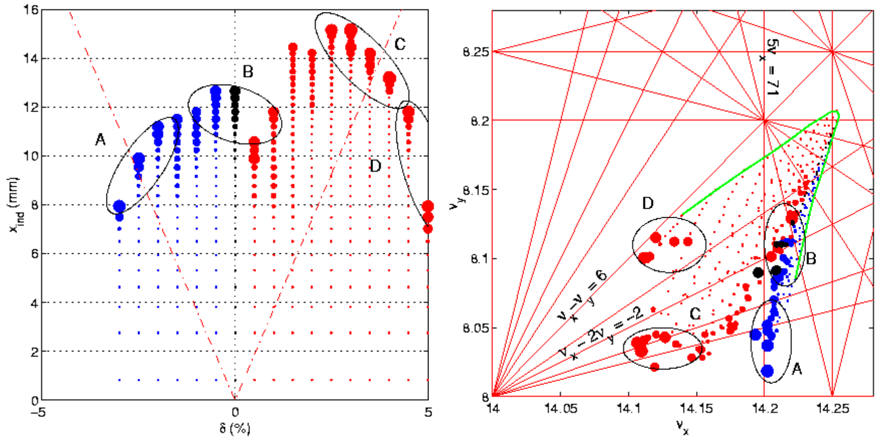


Fig 3: Measured momentum aperture in tune (right) and in configuration space (left) for a chromaticity of ($\xi_x$=0.4, $\xi_y$=1.4). Point size indicates relative beam loss and labels point out specific resonance areas responsible for these losses. Resonances up to the fifth order are shown in the tune space.

same data in frequency space. By recording the tunes of the particles after they have been kicked, one can clearly identify which resonance areas are causing the beam loss. By using this information, one can now understand (compare areas A-D in the plots) what caused particular loss regions. The knowledge gained as a result of these measurements allows us to adjust the machine parameters to improve the lifetime.

# References:

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